Nanostructured Scalable Thick-Film Magnetics

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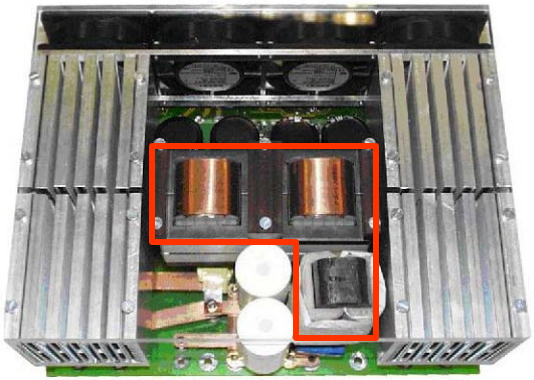
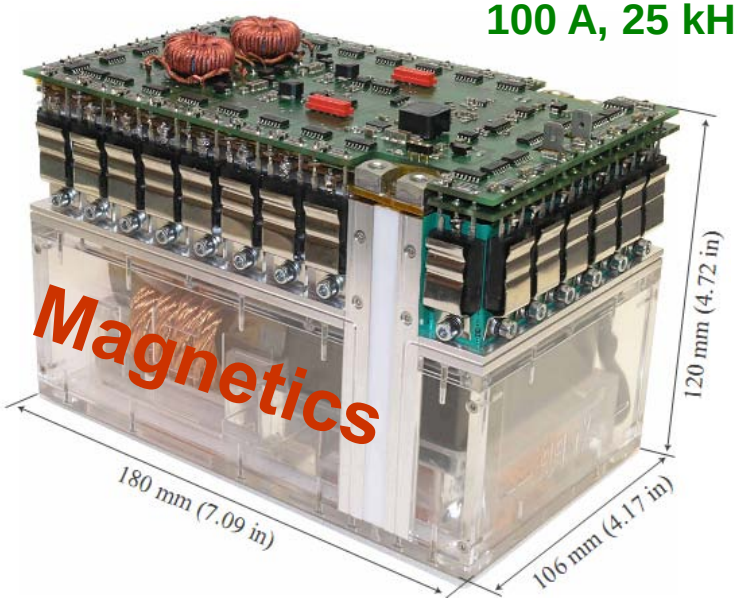
Magnetics In Power Conversion

- Magnetics (inductors and transformers) are required for most power conversion circuits, but are responsible for much of the
  - Size (volume and weight)
  - Power loss
  - Cost
  - Difficulty in design (long development cycles)



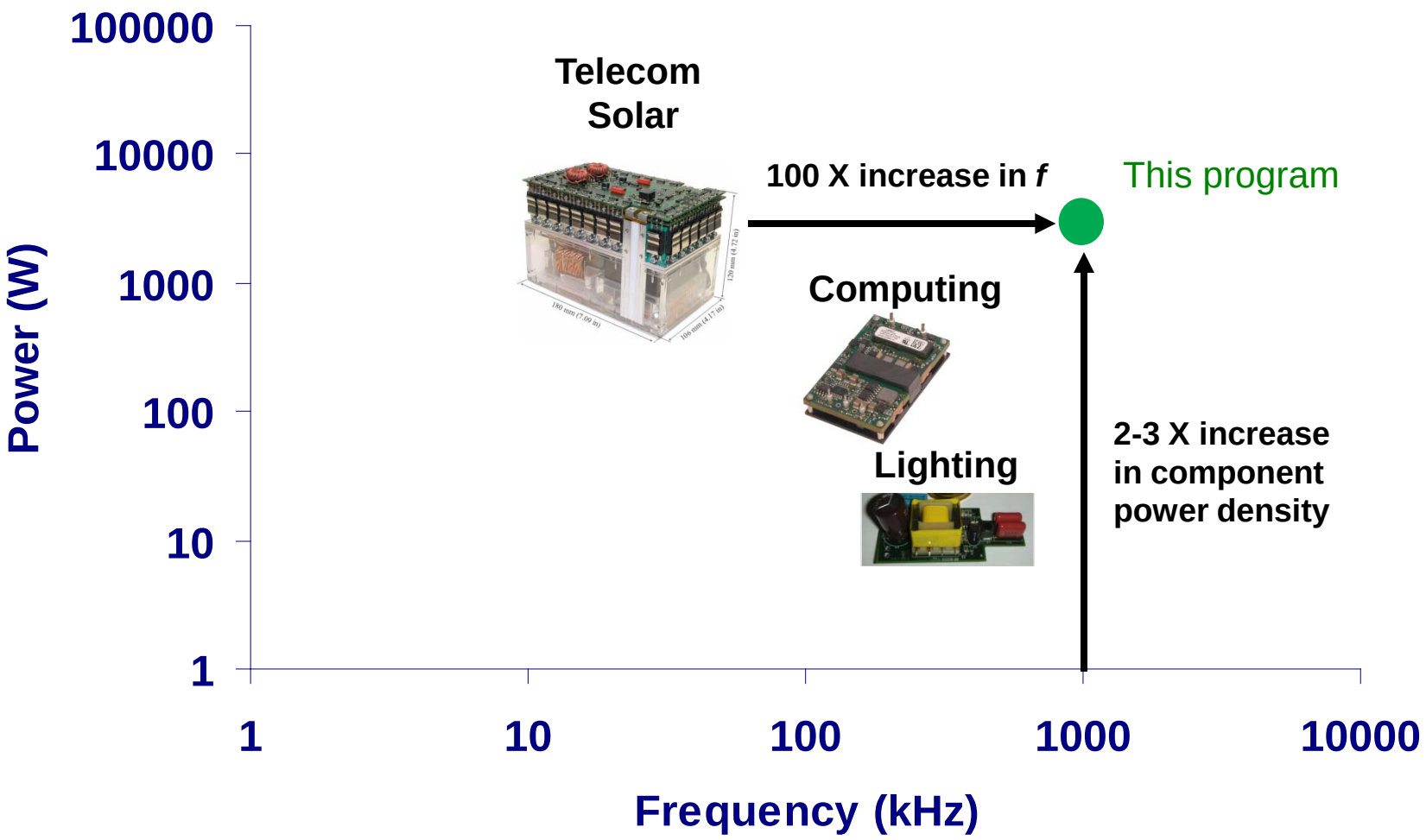
5 kW, 800 V to 48 V, 200 A, 25 kHz, 11 W/in^3

5 kW, 400 V to 48 V, 100 A, 25 kHz, 38 W/in^3

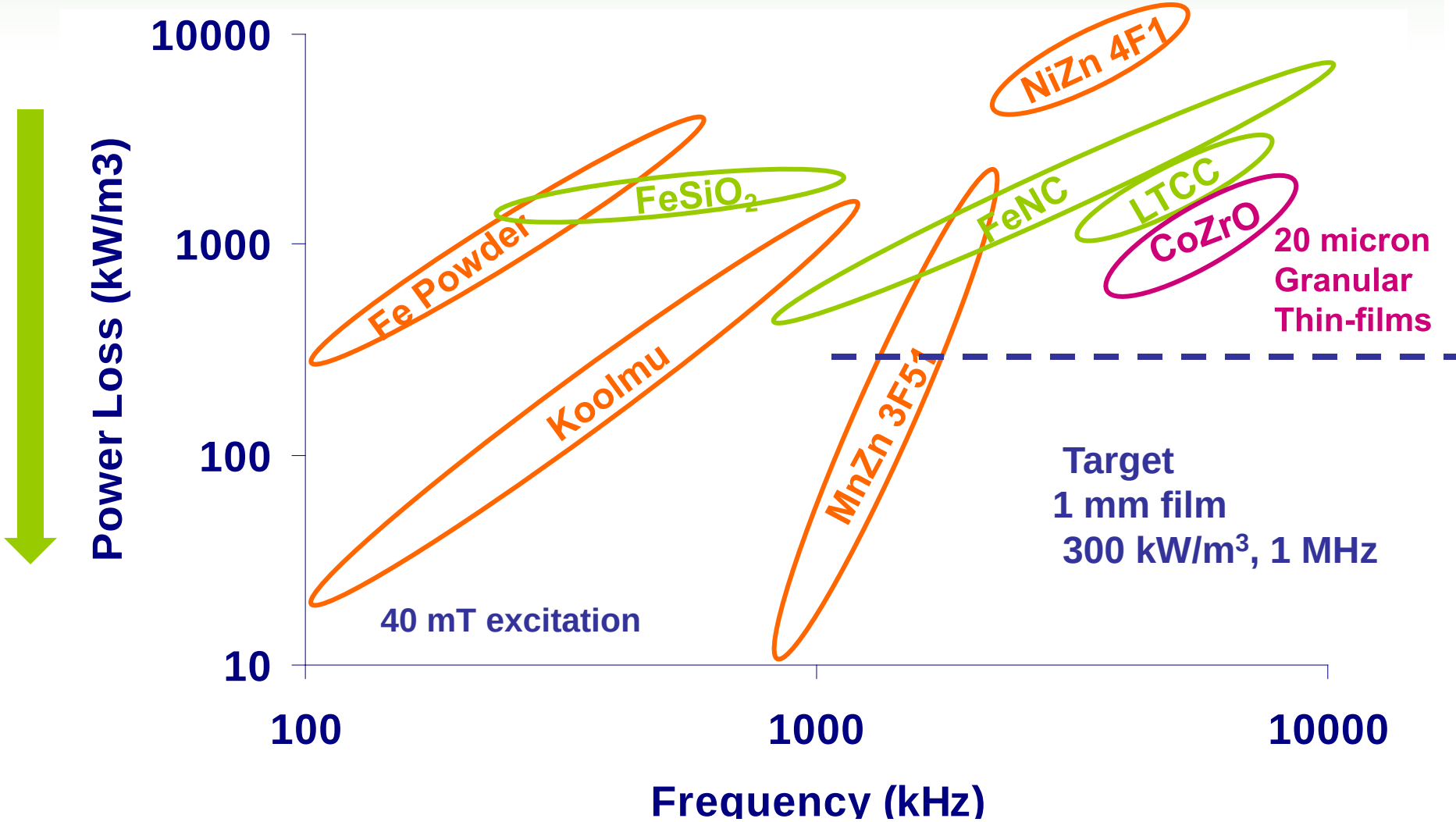


"An Optimized, 99% Efficient, 5 kW, Phase-Shift PWM DC-DC Converter for Data Centers and Telecom Applications", Kolar et al. 2010 International Power Electronics Conference.

Power Conversion Trends



State-of-the-Art Materials



Strategy and Targets

- Employ high-rate deposition processes to produce millimeter thick films
- Fabricate composite microstructures to reduce eddy current loss and enable high frequency operation
- Explore multiple metal/insulator compositions and connectivity patterns to minimize risk and expand application space

Electron Beam Physical Vapor Deposition

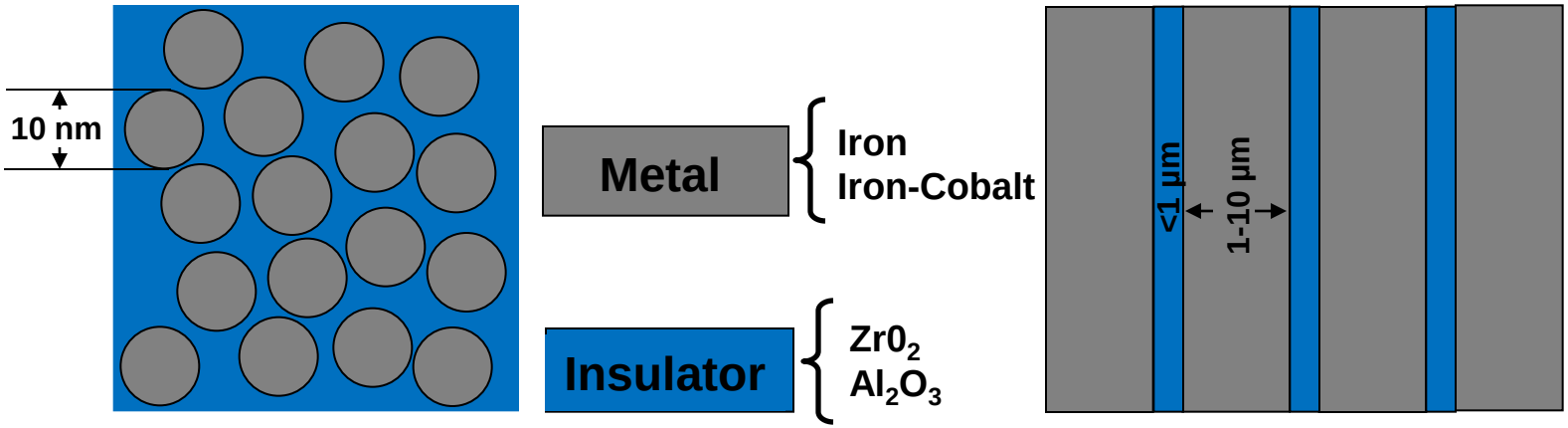
Material property targets

Property	Today	Target
Saturation magnetization	0.3 T	1 T
Coercivity	20-80 A/m	< 1 A/m
Resistivity	1 X 10^8 uΩ-cm	≥ 1000 uΩ-cm
Power loss	Saturated	≤ 300 kW/m^3, 1 T B_{sat} , 1 MHz
Thermal conductivity	5 W/m-C	≥ 10 W/m-C
Film Thickness	bulk	1 mm
Initial relative permeability	< 1000	< 1000
Maximum operating temperature	125 C	≥ 125 C

Thick-film Composite Microstructures

"Nanogranular"
Operating frequency: 1-100 MHz

"Multilayer"
Operating frequency: 100 kHz-10 MHz

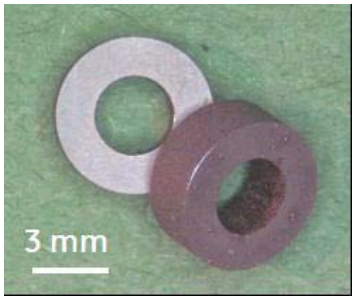


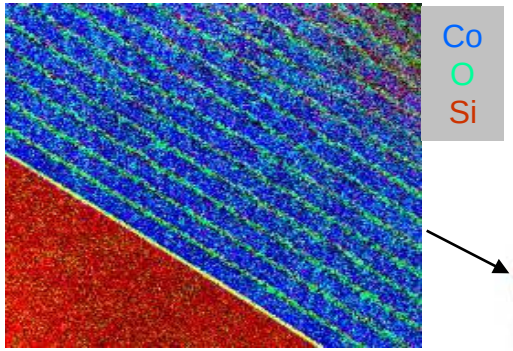
Insulator phase minimizes eddy current loss at operating frequencies

Iterative material development will identify candidate microstructures

Component Fabrication

Preliminary work at GE
Unoptimized mm-scale toroids





- Deposit mm-scale films
- Post deposition machining
  - –Laser machining
  - –Electric discharge machining
- Stack to form components
- Wind conductors

Subscale component precedes final component

Example fabrication approach

Program Overview

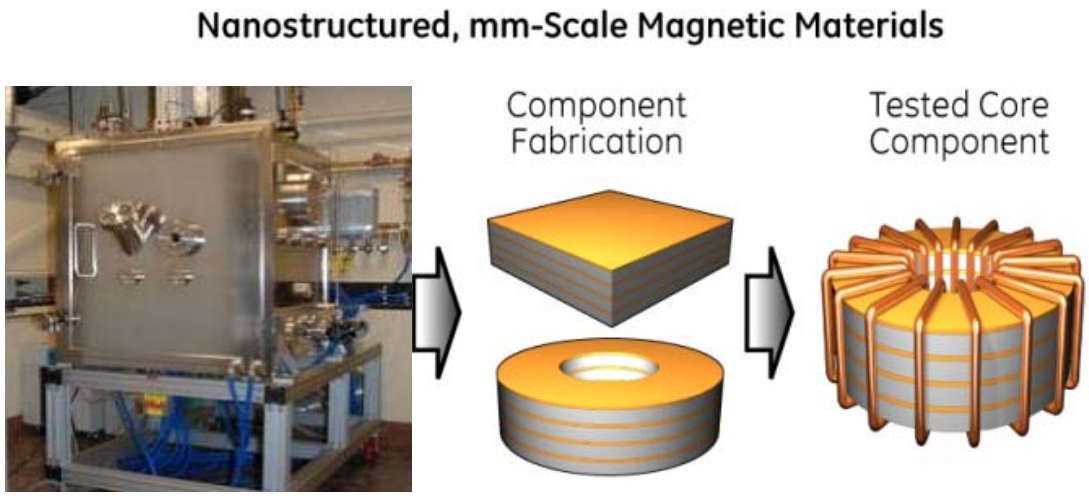
Technology Summary

Unprecedented nanostructured, millimeter-scale thick-film magnetic materials

Scalable physical vapor deposition

Prototype power magnetic component

"Proof-of-concept" Category 2, TRL2 to TRL3



Technology Impact

2 to 3x increase in power density of magnetics components

10–100x increase in switching frequency kW-level converters

Novel methods and new materials

Revolutionary Magnetic Materials for High-Efficiency, High-Density Power Conversion